Name:	Date:

Topic 2.3 Transport (Animals) – Page 1

(a) the similarities and differences in the vascular systems of animal groups:

- Earthworm — vascularisation, closed circulatory system and pumps, carriage of respiratory gases in blood
- Insects — open circulatory system, dorsal tube-shaped heart, lack of respiratory gases in blood
- Fish — single circulatory system
- Mammal — double circulatory system

(b) the mammalian circulatory system including the structure and function of heart and blood vessels and the names of the main blood vessels associated with the human heart

(c) the cardiac cycle and the maintenance of circulation to include graphical analysis of pressure changes, the role of sino-atrial node and Purkyne/ Purkinje fibres and the analysis of electrocardiogram traces to show electrical activity

(d) the function of red blood cells and plasma in relation to transport of respiratory gases, dissociation curves of haemoglobin of mammal (adult and foetus), including examination of microscope slides of erythrocytes

(e) the dissociation curves of some animals adapted to low oxygen level habitats e.g. llama, lugworm

(f) the Bohr effect and chloride shift

(g) the transport of nutrients, hormones, excretory products and heat in the blood

(h) the formation of tissue fluid and its importance as a link between blood and cells

SPECIFIED PRACTICAL WORK

- Scientific drawing of a low power plan of a prepared slide of T.S artery and vein, including calculation of actual size and magnification of drawing
- Dissection of mammalian heart

Prior to AS level you probably only looked at the structure of the heart as well as the basic structure and function of arteries, veins and capillaries.

		Completed
1.	Read about open and closed circulatory systems p 4–6 and answer the questions within the text.	
2.	Be clear what is meant by a single and double circulatory system Read p7	
3.	Label the heart on page 8 and answer the questions	
4.	Compare the structures of arteries, veins and capillaries. Complete the questions on p9-11	
6.	Read Toole and Toole Understanding Biology Textbook p429-433	

End of topic checklist for 2.3 Transport

Tick as appropriate:
RED: I do not know about this
AMBER: I have heard about this but have not learned this yet. I am unsure on this.
GREEN: I have heard about this and I have learned this. I am confident about this.

	Topic	RED	AMBER	GREEN
1.	Multicellular animals have a transport system.			
2.	Insects have an open circulatory system, with a dorsal tube shaped heart, and a fluid filled cavity (haemocoel).			
3.	The earthworm has a closed circulatory system, with blood pressure. Organs are not in direct contact with the blood. Respiratory gases are transported in the blood.			
4.	Mammals have a circulatory system comprising closed, double circulation and a heart with two atria and ventricles.			
5.	The major blood vessels of the heart include: aorta, vena cava, pulmonary veins, pulmonary arteries and coronary arteries.			
6.	The heart is a specialised organ having cardiac muscle, own blood supply, variation in the thickness of its walls and valves.			
7.	Large vessels have 3 main layers in the walls: tough collagen, elastic muscular layer to sustain pressure and endothelium to which is smooth to reduce friction; capillary walls are one cell thick.			
8.	Veins have a thinner muscle layer than arteries and along their length are semi-lunar valves to ensure flow in one direction.			
9.	Arteries have thick walls to resist pressure.			
10.	Arterioles adjust diameter to adjust blood pressure.			
11.	Capillaries have a small diameter and friction with the walls slows the blood flow. Although the diameter is small, there are many capillaries in the capillary bed, providing a large cross sectional area, which further reduces blood flow. The low velocity in very thin walled vessels enhances their ability to exchange materials with the surrounding tissue fluid.			
12.	Venules/veins have larger diameters and thinner walls than arterioles/arteries and the pressure is reduced; valves prevent back flow.			
13.	The cardiac cycle refers to a sequence of events that takes place during the beating of the heart. The sinoatrial node is spontaneously active and its excitation spreads out across the atria, causing them to contract, but is prevented from spreading to the ventricles by a thin layer of connective tissue. Excitation spreads via the atrioventricular node, through the Bundle of His to the apex of the ventricle. The bundle branches into Purkinje fibres in the ventricle walls, which carry the wave of excitation upwards through the ventricle muscle. The contraction of the ventricles is therefore delayed after the atria. The pressure changes in the atria, ventricles and aorta during the cardiac cycle can be analysed graphically. These pressure changes are responsible for the opening and closing of the valves.			
14.	When blood leaves the heart the highest pressures are found in the aorta and main arteries which show a rhythmic rise and fall which corresponds			

to ventricular contraction.			
15. Friction with vessel walls causes progressive pressure drop. Arterioles have a large total surface area and relatively narrow bore causing substantial reduction from aortic pressure. Their pressure depends on whether they are dilated or contracted.			
16. There is an even greater resistance in the capillaries with a larger cross-sectional area.			
17. The velocity of blood of blood flow is directly related to pressure. In the capillary beds the pressure drops further due to leakage from the capillaries into tissues.			
18. Return flow to the heart is non-rhythmic and the pressure in the veins is low but can be increased by the massaging effect of the muscles.			
19. Heart rate can be modified by hormones or the nervous system.			
20. Blood components carry gases – haemoglobin carries oxygen as oxyhaemoglobin.			
21. The functioning of different types of haemoglobin is demonstrated by plotting oxygen dissociation curves for normal mammalian haemoglobin compared to foetal haemoglobin.			
22. Oxygen dissociation curves for llama haemoglobin and lugworm demonstrate a physiological adaptation for life in oxygen-depleted conditions.			
23. The release of oxygen involved the Bohr effect where the lowered pH due to dissolving carbon dioxide reducing the oxygen affinity for haemoglobin, causing it to release oxygen where it is most required.			
24. Some carbon dioxide is transported in red blood cells, but most is converted in the red blood cells to bicarbonate, which is then dissolved in the plasma. The chloride shift refers to the influx of chloride ions into the red blood cells to preserve electrical neutrality as the bicarbonate leaves.			
25. The blood transports other substances in the blood plasma: digested food products, hormones, proteins, albumin, fibrinogen, antibodies and ions and it also distributes heat.			
26. Water and small solutes pass through the capillary endothelium at the beginning of the capillary beds. The hydrostatic pressure here (forcing liquid out) is greater than the osmotic pressure (drawing water in). At the end of the capillary bed the hydrostatic pressure has dropped to a low value and the water potential gradient causes an inward flow about 99% of the fluid that leaves the blood at the arterial end of the capillary bed returns at the venous end.			
27. The rest of the tissue fluid is returned via the lymphatic system.			

Transport in Animals
In larger animals, diffusion is simply too slow for all the cells to exchange materials quickly enough or in sufficient quantities to stay active and healthy.

An effective transport system will include:

- A fluid or medium to carry nutrients and (gases) around the body
- A pump to create pressure that will push the fluid around the body
- Exchange surfaces that enable (gases) and nutrients to enter the transport fluid and then leave the transport fluid where they are needed

Can you think of a reason why I put (gases) into brackets in the above statements?

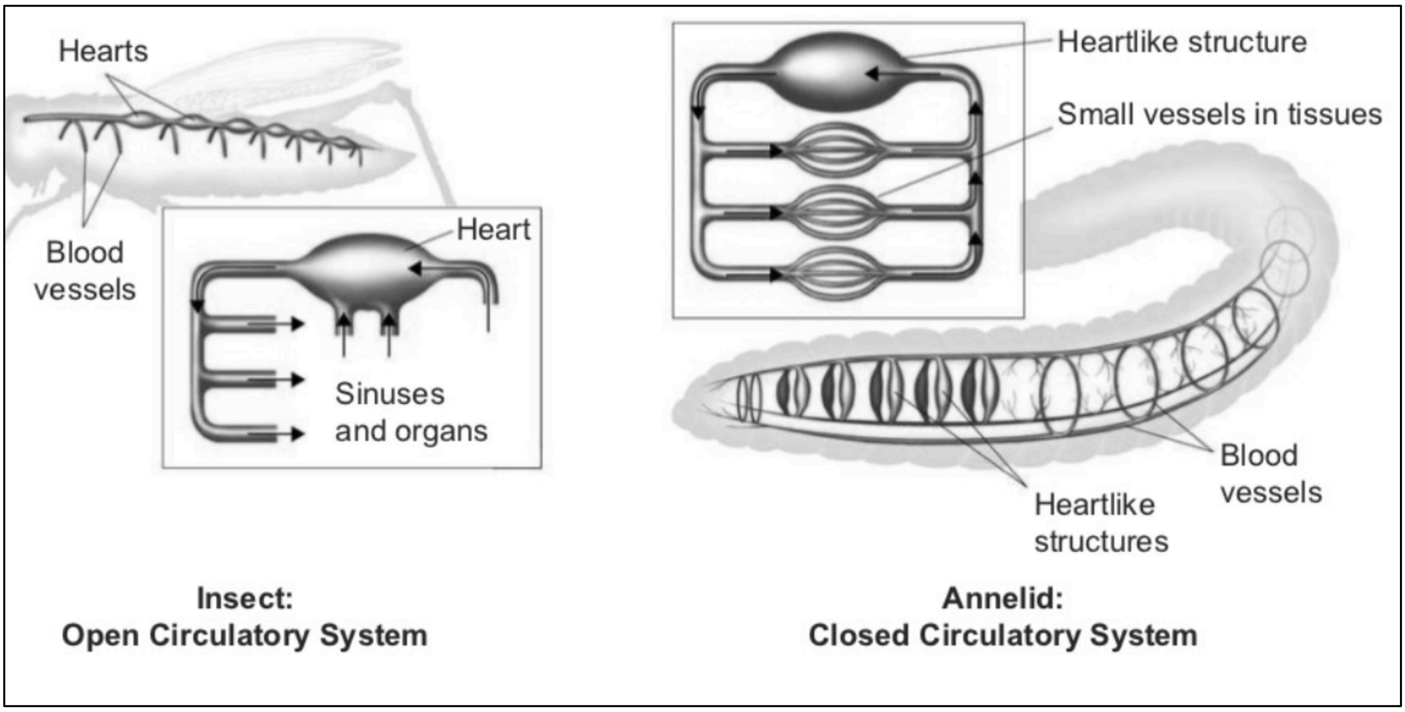
More efficient and well-developed transport systems will also have:
- Tubes or vessels to carry the transport (usually blood).
- Two circuits, one to puck up gases from the gas exchange surface and a second to then deliver it to the places it is needed in the body.

Open and Closed Circulatory Systems

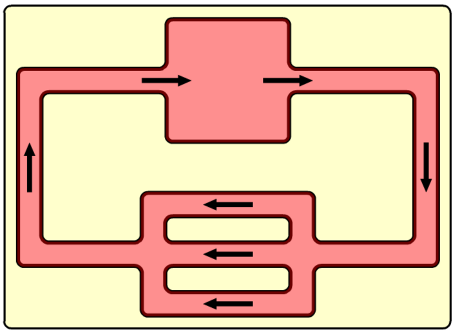
Circulatory systems can be classified as:
- Open systems, e.g. insects
- Closed systems e.g. fish and mammals

Open Circulatory System
In an open circulatory system the artery, which leaves the heart, branches into short arteries which themselves open into large, blood filled spaces collectively called haemocoel. Blood from these spaces gradually returns to the heart through a few open-ended veins. The blood seeps around the organs which are literally bathed in blood.

Label where you think the 'short arteries', 'haemocoel' and 'open-ended veins' would be on the diagram below on the left.



Closed Circulatory System
In a closed circulatory system blood is enclosed within blood vessels and is distinct from the tissue fluid. Blood is moved from a muscular pump to the tissues of the body and back again entirely through blood vessels. High pressure in the capillaries forces water and other small molecules through the thin capillary walls to form a tissue fluid that bathes the cells. Label the heart and capillaries below.



Which system do you think will have the highest blood pressure and why?

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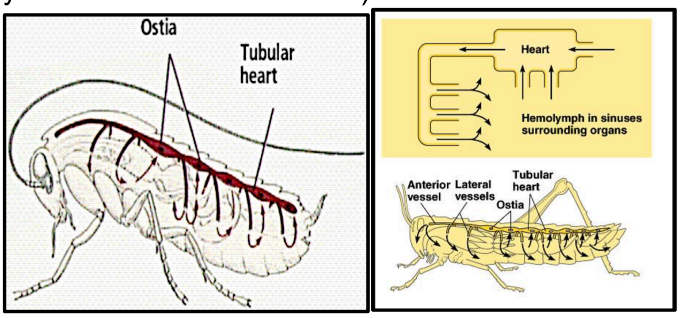
Insect Circulatory System – An example of an Open Circulatory System

In an insect there is a muscular pumping organ much like a heart. This is a long tube that lies under the dorsal (upper) surface of the insect. The heart pumps the blood towards the head via peristalsis. At the forward end of the heart nearest the head, the blood simply pours out into the spaces of the body cavity called haemocoel. (the blood is referred to as haemolymph in the diagram below and the sinuses refer to the body cavities called haemocoel).



The blood bathes the tissues directly; exchange of materials takes place with the cells. Blood slowly returns to the heart. Valves and muscular contractions move the blood towards the heart where it enters back into the heart through pores called ostia.

Do you think that the blood will contain a respiratory pigment, explain your answer:

______

______

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This open circulatory system is under low pressure and so it seen as being not very efficient.
Why do you think it works for insects?

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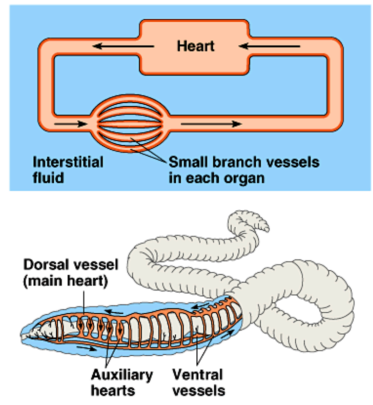
______

Closed Circulatory Systems (shown by annelids, fish and mammals)



(b) Closed circulatory system

Annelids

An annelid has a closed circulatory system, blood never comes into direct contact with the tissues and body cavities of the body, it is always confined to blood vessels.

A simple organism, the earthworm (an example of an annelid) has a closed circulation system. It has dorsal and ventral vessels running the length of its body and these are connected via 5 pairs of 'pseudohearts'. Blood is pushed through the vessels by the pumping action of the 'pseudohearts'.

Summary of Open and Closed Circulatory Systems

One or muscular structures (usually called hearts) which pump fluid (usually called blood) around the body. The fluid can be transported in an open or closed system.

Open Circulatory System

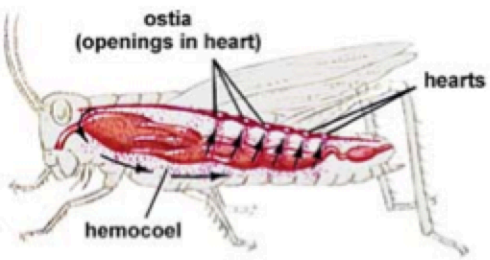
Shown by arthropods and molluscs.

Blood bathes organs directly in spaces or sinuses called haemocoel.

Blood is under low pressure and slowly drains back through the ostia into the heart.

Little control over the direction of blood flow.

In insects is does not transport respiratory gases so there are no blood pigments.



Closed Circulatory System

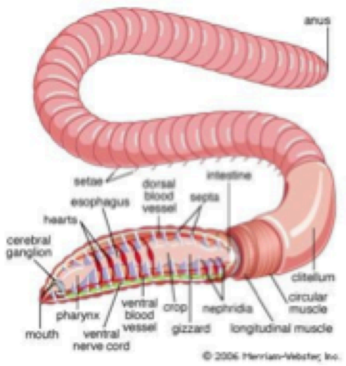
Called a closed system.

Shown by annelids, echinoderms and all vertebrates.

Blood stays in closed vessels, there is no direct contact with the body tissues and organs.

Heart is muscular and can be used to produce a high pressure within the vessels.

Distribution to tissues can be altered.
Blood pigments are used.



Single and Double Circulation

All chordates possess a closed circulatory system. There are two types.

- **Single Circulatory Systems** e.g. fish
- **Double Circulatory Systems** e.g. mammals

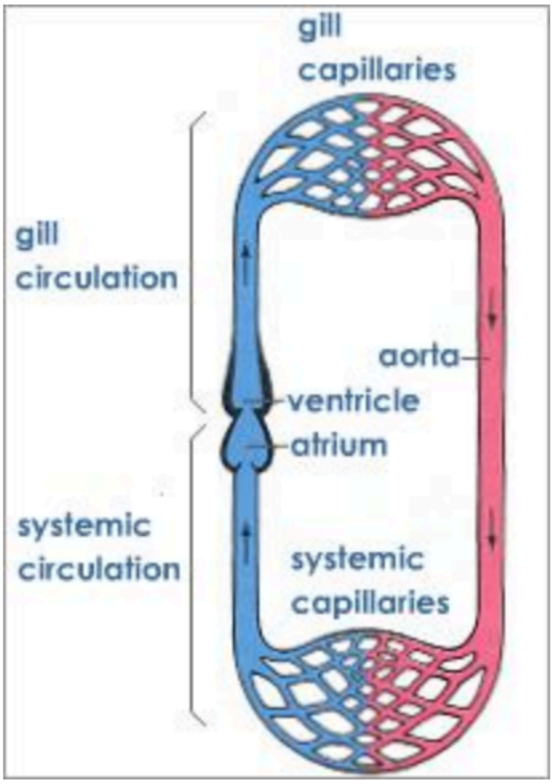
Fish – Single Circulatory System

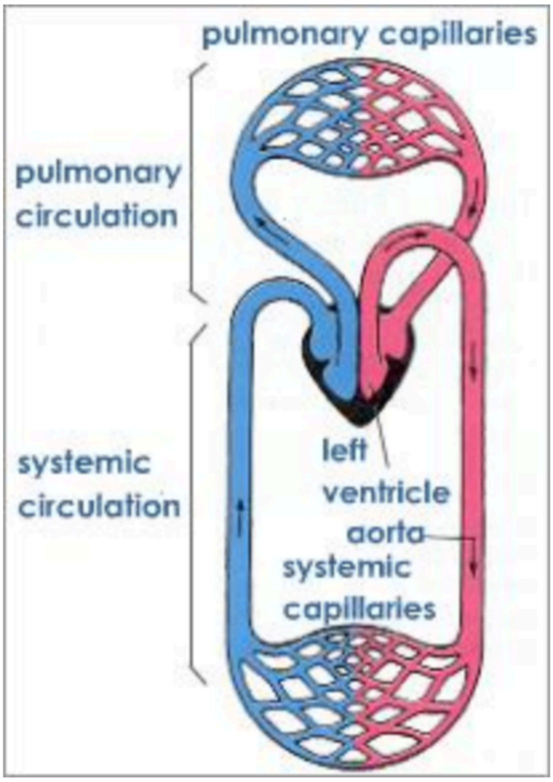
In fish, deoxygenated blood is pumped by the heart to the gills, the oxygenated blood then flows from the gills around the body and then returns to the heart. The blood flows through the heart only once for every complete circuit of the body. This is why it is called a single circulatory system.

Problems
When the blood flows to the gills it has to go through the capillary networks of the lamellae before travelling around the rest of the body and reaching more capillary networks.

Capillaries offer resistance to blood flow, this leads to a large drop in blood pressure. This means that the flow of blood back from the tissues to the heart is extremely slow and sluggish.

Single Circulation **Double Circulation**



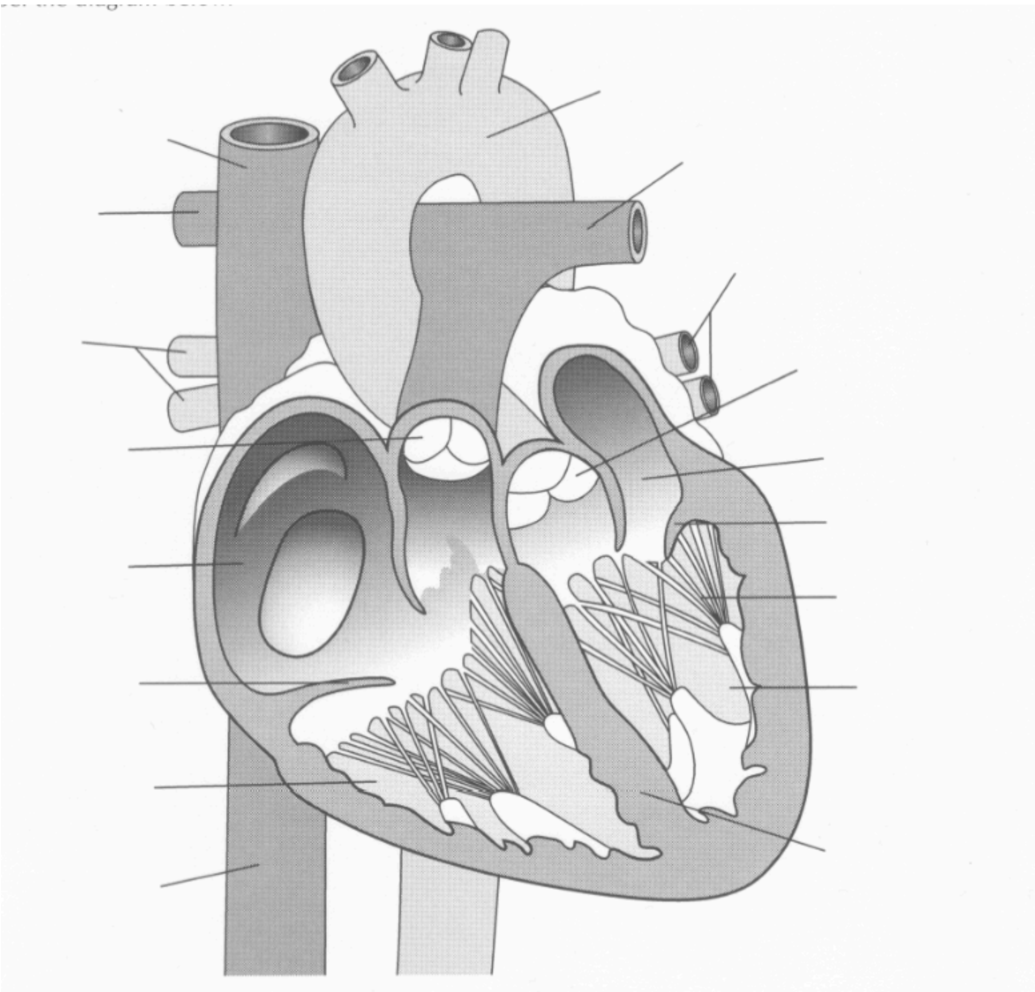


Mammals - Double Circulatory System

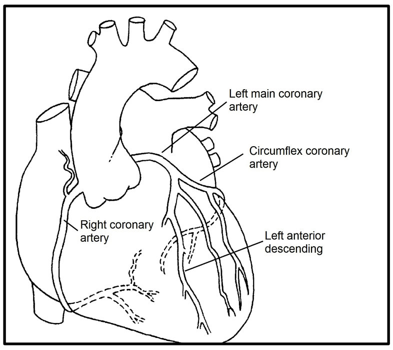
The problems of a drop in blood pressure are overcome with a double circulatory system in which deoxygenated blood is pumped from the heart to the lungs, after which the oxygenated blood is returned to the heart and is then pumped around the rest of the body. So the blood flows twice for each complete circuit of the body. Mammalian hearts are being divided into completely separate right and left sides separates the deoxygenated and oxygenated blood.

What do the terms pulmonary and systemic mean?

The Heart



Highlight the aorta, vena cava, pulmonary veins, pulmonary arteries and valves.



Explain the importance of the blood vessels that run over the surface of the **cardiac muscle**, the **coronary arteries**:

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Explain why the left ventricle has a thicker more muscular wall than the right ventricle.

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What is the purpose of the valves?

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What is special about cardiac muscle?

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Arteries

In vertebrates, arteries are the blood vessels that carry blood away from the heart to the capillaries within the tissues. The large arteries that leave the heart divide into medium-sized (distributing) arteries. Within the tissues and organs, these distribution arteries branch to form very small vessels called **arterioles**, which deliver blood to capillaries. Arterioles lack the thick layers of arteries and consist only of an endothelial layer wrapped by a few smooth muscle fibres at intervals along their length. Resistance to blood flow is altered by contraction (**vasoconstriction**) or relaxation (**vasodilation**) of the blood vessel walls, especially in the arterioles. Vasoconstriction increases resistance and leads to an increase in blood pressure whereas vasodilation has the opposite effect. This mechanism is important in regulating the blood flow into tissues.

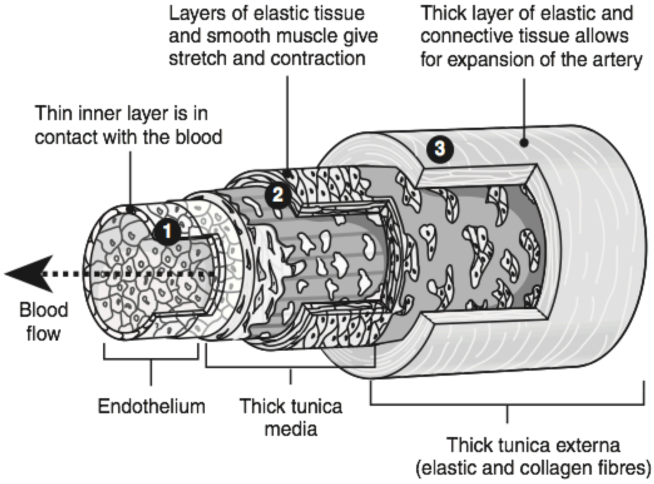
Arteries

Arteries have an elastic, stretchy structure that gives them the ability to withstand the high pressure of blood being pumped from the heart. At the same time, they help to maintain pressure by having some contractile ability themselves (a feature of the central muscle layer). Arteries nearer the heart have more elastic tissue, giving greater resistance to the higher blood pressures of the blood leaving the left ventricle. Arteries further from the heart have more muscle to help them maintain blood pressure. Between heartbeats, the arteries undergo elastic recoil and contract. This tends to smooth out the flow of blood through the vessel.

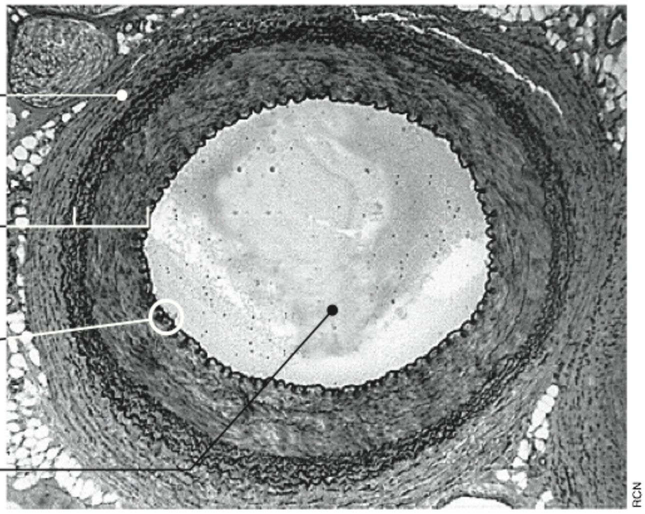
Arteries comprise three main regions (right):

1. A thin inner layer of epithelial cells called the **endothelium** lines the artery.
2. A central layer (the **tunica media**) of elastic tissue and smooth muscle that can stretch and contract.
3. An outer connective tissue layer (the **tunica externa**) has a lot of elastic tissue.

Artery Structure



Cross section through a large artery



(a)

(b)

(c)

(d)

Large blood vessels contain three main layers in their walls tough collagen, elastic muscular layer and endothelium as the inner layer.

Describe the how the blood is flowing in the arteries as it leaves the heart:

Describe how the structure of the artery adapts it to cope with the blood leaving the heart:

Arteries branch into smaller arterioles that carry blood to the capillary beds. They can adjust their diameter. How do they do this and why would it be useful?

Veins

Veins are the blood vessels that return blood to the heart from the tissues. The smallest veins (**venules**) return blood from the capillary beds to the larger veins. Veins and their branches contain about 59% of the blood in the body. The structural differences between veins and arteries are mainly associate with differences in the relative thickness of the vessel laye and the diameter of the lumen. These, in turn, are related to tl vessel's functional role.

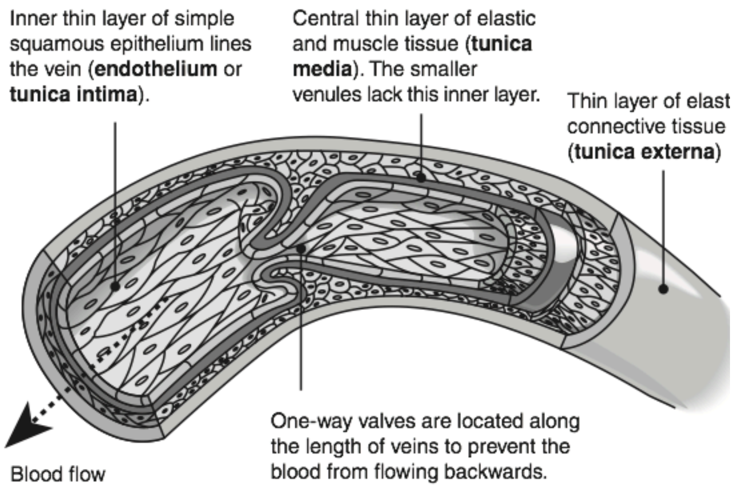
Veins

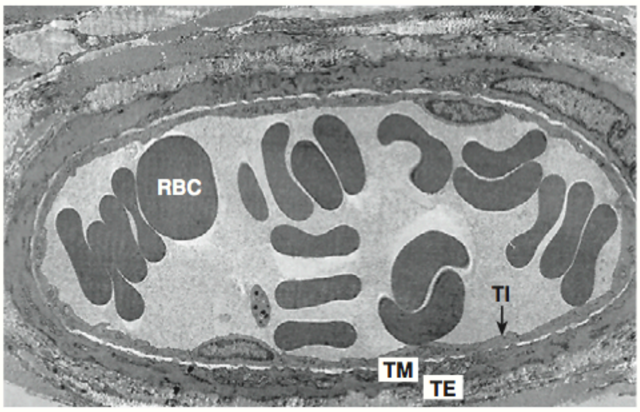
When several capillaries unite, they form small veins called **venules**. The venules collect the blood from capillaries and drain it into **veins**. Veins are made up of essentially the same three layers as arteries but they have less elastic and muscle tissue and a larger **lumen**. The venules closest to the capillaries consist of an **endothelium** and a tunica externa of connective tissue. As the venules approach the veins, they also contain the tunica media characteristic of veins (right). Although veins are less elastic than arteries, they can still expand enough to adapt to changes in the pressure and volume of the blood passing through them. Blood flowing in the veins has lost a lot of pressure because it has passed through the narrow capillary vessels. The low pressure in veins means that many veins, especially those in the limbs, need to have valves to prevent backflow of the blood as it returns to the heart.

Dan Butler

If a vein is cut, as is shown in this severe finger wound, the blood oozes out slowly in an even flow, and usually clots quickly as it leaves. In contrast, arterial blood spurts rapidly and requires pressure to staunch the flow.

Vein Structure





EII

Above: TEM of a vein showing red blood cells (RBC) in the lumen, and the tunica intima (TI), tunica media (TM), and tunica externa (TE).

Blood enters venules from the capillary beds and the venules converge into veins.

Describe the blood in the veins.

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Describe how the structure and location of veins adapts them to cope with returning blood to the heart:

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Contrast the structure and function of an artery with a vein.

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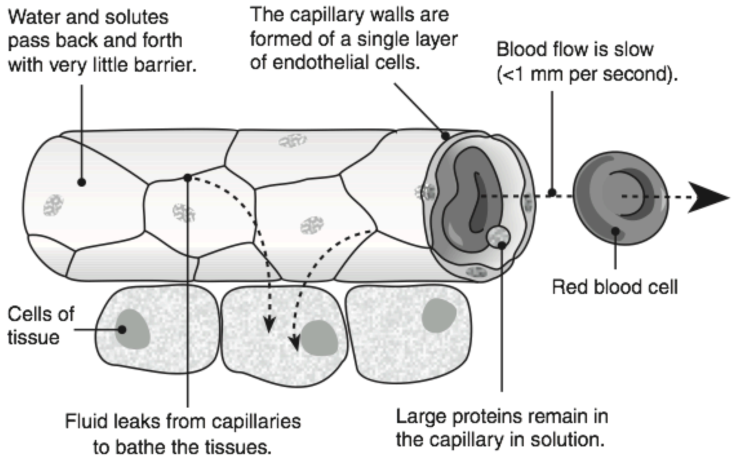
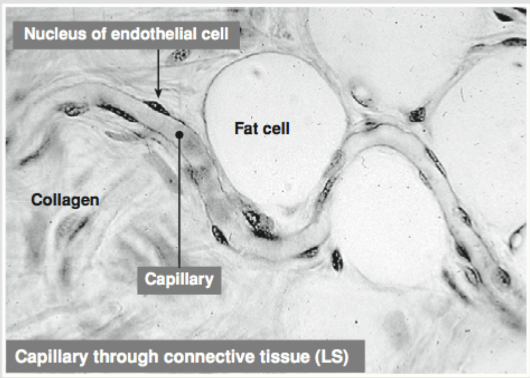
Capillaries

In vertebrates, capillaries are very small vessels that connect arterial and venous circulation and allow efficient exchange of nutrients and wastes between the blood and tissues. Capillaries form networks or beds and are abundant where metabolic rates are high. Fluid that leaks out of the capillaries has an essential role in bathing the tissues. The movement of fluid into and out of capillaries depends on the balance between the blood (hydrostatic) pressure (HP) and the solute potential (ψs) at each end of a capillary bed. Not all the fluid is returned to the capillaries and this extra fluid must be returned to the general circulation. This is the role of the **lymphatic system**; a system of vessels that parallels the system of arteries and veins. The lymphatic system also has a role in internal defence, and in transporting lipids absorbed from the digestive tract. Note: A version of this activity (without reference to solute potential terminology), is available on the web and the Teacher Resource CD-ROM.

Exchanges in Capillaries

Blood passes from the arterioles into capillaries: small blood vessels with a diameter of just 4-10 µm. Red blood cells are 7-8 µm and only just squeeze through. The only tissue present is an **endothelium** of squamous epithelial cells. Capillaries form networks of vessels that penetrate all parts of the body. They are so numerous that no cell is more than 25 µm from any capillary. It is in the capillaries that the exchange of materials between the body cells and the blood takes place. Blood pressure causes fluid to leak from capillaries through small gaps where the endothelial cells join. This fluid bathes the tissues, supplying nutrients and oxygen, and removing wastes (right).The density of capillaries in a tissue is an indication of that tissue's metabolic activity. For example, cardiac muscle relies heavily on oxidative metabolism. It has a high demand for blood flow and is well supplied with capillaries. Smooth muscle is far less active than cardiac muscle, relies more on anaerobic metabolism, and does not require such an extensive blood supply.





Capillaries are found near almost every cell in the body. In many places, the capillaries form extensive branching networks. In most tissues, blood normally flows through only a small portion of a capillary network when the metabolic demands of the tissue are low. When the tissue becomes active, the entire capillary network fills with blood.

The diameter of capillaries is small and friction with the walls will slow down blood flow.
This slow velocity will enhance their function of exchange.

Compare the structures and functions of arteries, veins and capillaries.

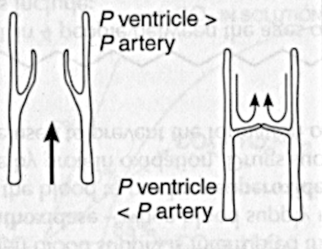
Draw a table for comparison purposes:

e.g.

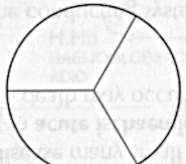
Feature	Artery	Vein	Capillary
Description of blood in vessel	Pulsating and at high pressure	Slow Moving, low pressure.	Slow moving.
Function	To transport blood away from the heart	To transport blood back to the heart	Exchange of materials, form tissue fluid

Mammalian heart structure and function

Pulmonary (semilunar) valve: has three cusps or watchpocket flaps which are forced together, then the pressure in the pulmonary artery exceeds that in the right ventricle, preventing backflow of blood into the relaxing chambers of the heart.



Tricuspid (right atrioventricular) valve: has three fibrous flaps with pointed ends which point into the ventricle. The flaps are pushed together when the ventricular pressure exceeds the atrial pressure so that blood is propelled past the inner edge of the valve through the pulmonary artery instead of through the valve and back into the atrium.



Superior (anterior) vena cava: carries deoxygenated blood back to the right atrium of the heart. As with other veins the wall is thin, with little elastic tissue or smooth muscle. In contrast to veins returning blood from below the heart there are no venous valves, since blood will return under the influence of gravity.

Volume: the same volume of blood passes through each side of the heart. Both ventricles pump the same volume of blood.

This is important to remember! If this wasn't true all the blood would end up in either the body (systemic circuit) or the lungs (pulmonary circuit).

Aorta: carries oxygenated blood from the left ventricle to the systemic circulation. It is a typical elastic (conducting) artery with a wall that is relatively thick in comparison to the lumen, and with more elastic fibres than smooth muscle. This allows the wall of the aorta to accommodate the surges of blood associated with the alternative contraction and relaxation of the heart - as the ventricles contract the artery expands and as the ventricle relaxes the elastic recoil of the artery forces the blood onwards.

Pulmonary arteries

Left atrium

Right atrium

Right ventricle: generates pressure to pump deoxygenated blood to pulmonary circulation.

Myocardium is composed of cardiac muscle: **intercalated discs** separate muscle fibres, strengthen the muscle tissue and aid impulse conduction; **cross-bridges** promote rapid conduction throughout entire myocardium; **numerous mitochondria** permit rapid aerobic respiration. Cardiac muscle is **myogenic** (can generate its own excitatory impulse) and has a **long refractory period** (interval between two consecutive effective excitatory impulses), which eliminates danger of cardiac fatigue.

The pressure generated by the left ventricle must be greater than that generated by the right ventricle as the systemic circuit is more extensive than the pulmonary circuit.

The pressure generated by the atria can be less than that generated by the ventricles since the distance from atria to ventricles is less than that from ventricles to circulatory system.

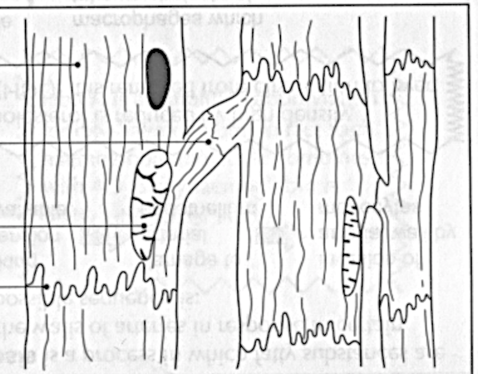
Aortic (semilunar) valve: prevents backflow from aorta to left ventricle.

Bicuspid (mitral, left atrioventricular) valve: ensures blood flow from left ventricle into aortic arch.

Left ventricle: generates pressure to force blood into the systemic circulation.

Chordae tendinae: short, inextensible fibres – mainly composed of collagen – which connect to free edges of atrioventricular valves to prevent 'blow-back' of valves when ventricular pressure rises during contraction of myocardium.

Papillary muscles: contract as wave of excitation spreads through ventricular myocardium and tighten the chordae tendineae just before the ventricles contract.



Mammalian double circulation comprises **pulmonary** (heart – lung – heart) and **systemic** (heart – rest of body – heart) **circuits**. The complete separation of the two circuits permits rapid, high-pressure distribution of oxygenated blood essential in active, endothermic animals. The circuits are named for the organ or system which they service – thus each kidney has a **renal** artery and vein. Each organ has an artery bringing oxygenated blood and nutrients, and a vein removing deoxygenated blood and waste.

Pulmonary artery: delivers deoxygenated blood to the lungs for reoxygenation.

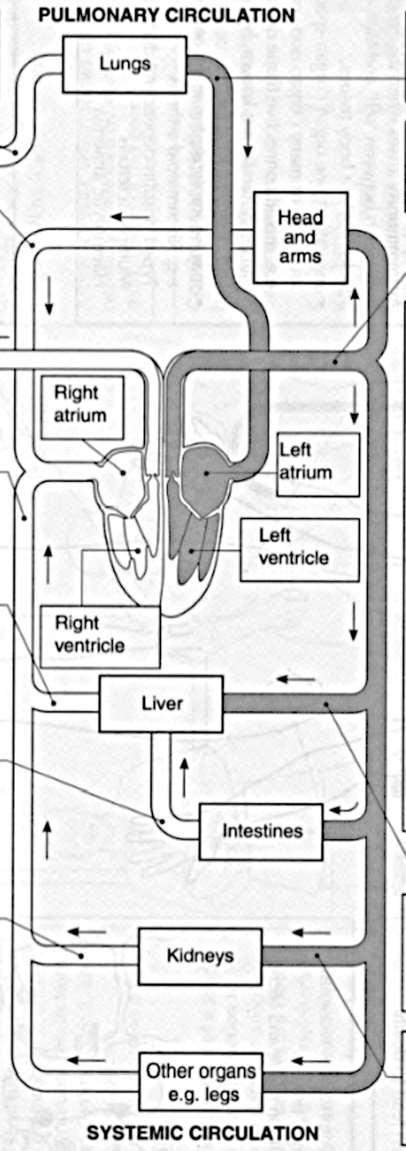
Superior vena cava: carries deoxygenated blood back to the right atrium from the head and forelimbs. The venous return to the heart initiates the expansion which triggers the sino-atrial node to fire the impulse which generates the heart beat.

Inferior vena cava: returns deoxygenated blood at low pressure to the right atrium of the heart.

Hepatic vein: delivers blood with an optimum concentration of solutes (particularly glucose) from the liver to the general circulation.

Hepatic portal vein: transports blood with a very variable solute concentration from the site of solute uptake (the gut) to the site of storage or regulation (the liver).

Renal veins: return deoxygenated blood with a reduced concentration of urea and creatinine, and a regulated pH and Na^+/K^+ ratio, from the kidneys to the general circulation.



Pulmonary veins: return oxygenated blood at low pressure to the left atrium of the heart.

Aorta: the principal vessel which distributes oxygenated blood at high pressure to the systemic circulation.

The **flow of blood** is maintained in three ways:

1. **The pumping action of the heart:** the ventricles generate pressures great enough to drive blood through the arteries into the capillaries.
2. **Contraction of skeletal muscle:** the contraction of muscles during normal movements compress and relax the thin-walled veins causing pressure changes within them. Pocket valves in the veins ensure that this pressure directs the blood to the heart, without backflow.
3. **Inspiratory movements:** reducing thoracic pressure caused by chest and diaphragm movements during inspiration helps to draw blood back towards the heart.

Hepatic artery: delivers oxygenated blood to the liver - this organ is so active metabolically that oxygen demands are very high.

Renal artery: carries blood with high O_2 concentration and high concentrations of solutes such as urea, creatinine and Na^+.

Fish have a single circulation: blood flows through the heart only once for each complete circuit of the body:

- rapid fall in velocity and pressure as blood leaves the gills
- pressure too low for efficient kidney function in mammals.